Waves, Turbulence and Boundary Layers

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Grant Number: N00014-01-1-0170
http://www.aos.princeton.edu/WWWPUBLIC/glm/mellor.html

LONG-TERM GOALS

The long-term goal is to develop a unified fully coupled ocean wave - circulation model. This has not been possible previously since the interaction terms (e.g., wave radiation stress terms) are, a priori, vertically integrated (Phillips 1977) and the non-wave induced velocities have been assumed to be vertically constant. Following Mellor (2002), I plan to develop theory and computations for turbulent bottom boundary layers to account for shallow water wave and streaming effects.

OBJECTIVES

1. Derive the three-dimensional, wave energy and momentum equations and the concommitant interaction terms.

2. For turbulence closure models that make use of the turbulence kinetic energy equation (e.g., the Mellor-Yamada model, 1982) determine the changes that must be made to fully recognize surface waves including transfer of wave energy to turbulence energy and transfer of wind stress to water column momentum.

3. Develop a coupled wave-current numerical model and compare with field and laboratory observations including those from CBLAST.

Objective 1 has been accomplished. Objectives 2 and 3 are simulataneously in progress.

APPROACH

The research combines theory and numerics, making use of data obtained by observationalists.

WORK COMPLETED

During the course of the project, five papers have been completed and a sixth is in progress.

Surprisingly, surface wave equations appropriate to three-dimensional ocean models had not been presented in the literature; only vertically averaged equations have been available (Phillips 1977) and are not suitable for wave models interacting with three-dimensional circulation models. I believe that the paper, Mellor (2003), has now corrected this major deficiency.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2005		**00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Waves, Turbulence and Boundary Layers	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Princeton University,Program in Atmospheric and Oceanic Sciences,Princeton,NJ,08544**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The long-term goal is to develop a unified fully coupled ocean wave - circulation model. This has not been possible previously since the interaction terms (e.g., wave radiation stress terms) are, a priori, vertically integrated (Phillips 1977) and the non-wave induced velocities have been assumed to be vertically constant. Following Mellor (2002), I plan to develop theory and computations for turbulent bottom boundary layers to account for shallow water wave and streaming effects.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

The paper by Mellor and Blumberg (2004) combines the Mellor-Yamada (1982) turbulence closure model with the Craig-Banner (1994) wave breaking parameterization whereby turbulence energy due to wave breaking is injected into the top of the surface boundary layer. Correspondence between the principal empirical assumption of Craig and Banner and the data of Terray et al. (1996) was demonstrated. However, this process will be subsumed into the overall model as discussed next.

A new paper, Mellor (2005) is meant to present a version of Mellor (2003) sans detailed derivation. It develops energy pathways between the circulation, wave and turbulence modules. It also adds more physics such the bottom layer streaming effects and compares the present three-dimensional wave-current equations with those by McWilliams and Restrepo (1999)

I spent three Spring months at the Technical University of Delft with the idea that POM (Princeton Ocean Model) might be coupled with SWAN (Simulating Waves Nearshore). For several reasons (one is SWAN's 30,000 lines of code) this turned out to be impractical. Together with Mark Donelan, I therefore decided to build a new wave model which is relatively simple but sufficiently comprehensive and is structured for coupling with POM or any other circulation model.

The work described here has proceeded in consultation with Mark Donelan of the University of Miami, Gene Terray and others at the Woods Hole Oceanographic Institute, scientists at the Technical University of Delft, Alan Blumberg of Stevens Institute of Tecnology and Tal Ezer and Leo Oey of Princeton University.

RESULTS

During the report fiscal year, the principal result has been the revision and acceptance of Mellor (2005) and submission of a paper, Mellor and Donelan (2006). The latter paper describes the development of a new surface wave model. While the model is a stand-alone wave model, it is specifically designed to be coupled with a circulation model; we will do so with the Princeton Ocean Model (POM), but the wave model should be conveniently connected to any circulation model.

Figure 1 describes an application of the wave model. Waves crossing a Gulf Stream-like jet are distorted in amplitude and mean wave propagation angle. The paper also includes comparison with fetch and duration limited data.

Work in progress deals with findings in Mellor (2003, 2005) related to the surface boundary layer; now, it is understood that the wind stress is delivered to the water column momentum via pressure rather than Reynolds stress.

IMPACT/APPLICATIONS

I believe that the development of a comprehensive one-stop, relatively simple wave-current ocean model will be an important contribution to the numerical ocean modeling community for forecasting and climate reasearch and for deep to shallow water, including ultimately, the surf zone. It will obviate the need to patch together separate models with disconnected physics.

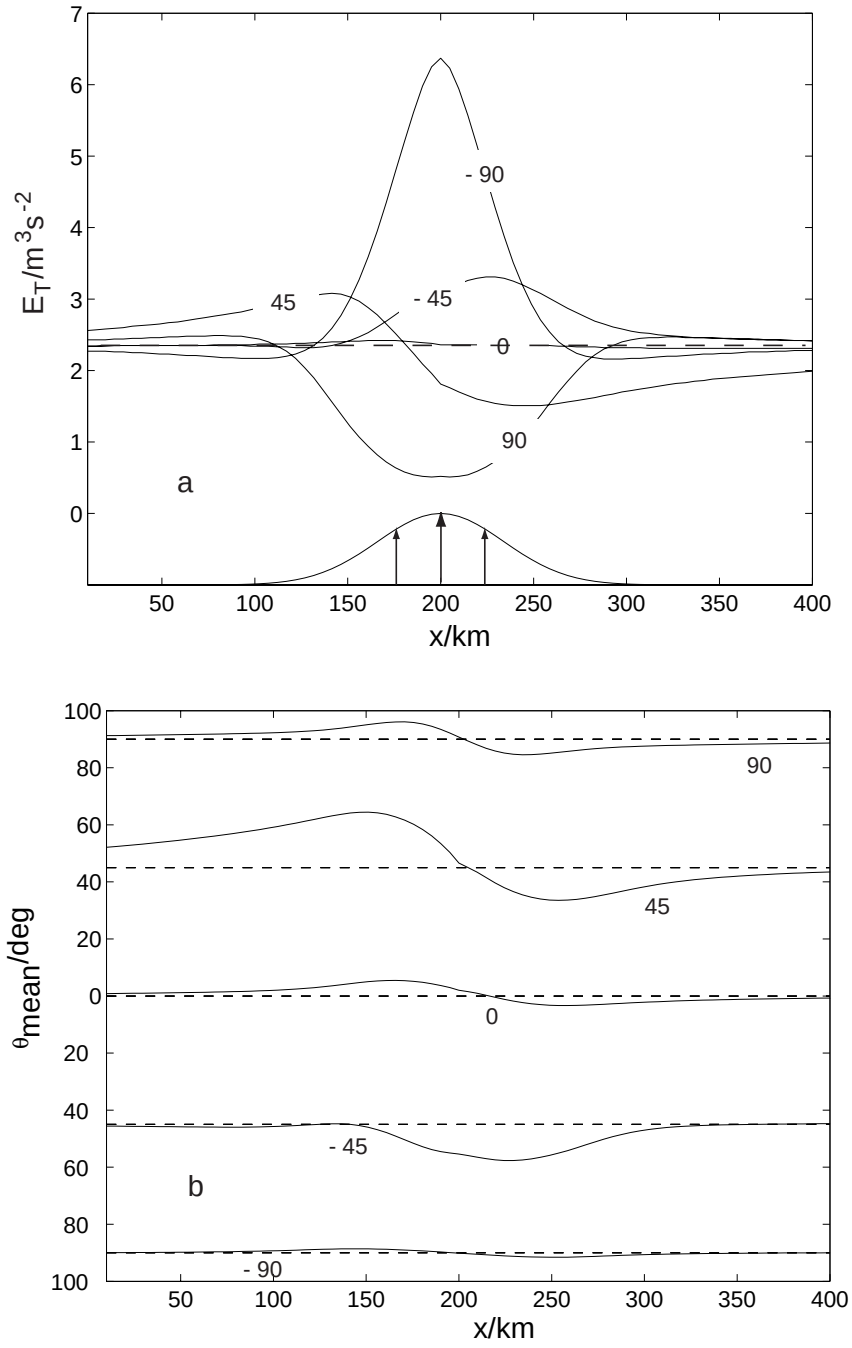

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Figure 1. The influence of a northward Gulf Stream like jet (maximum velocity = 2 m s^{-1}) on waves forced by 10 m s^{-1} winds whose angle varies from 90^o (northward; wind and jet velocities in the same direction) to -90^o (southward; wind and jet velocities in opposite directions). (a) The variation of wave energy. The dashed line is the background fully developed wave field in the absence of the jet. (b) The variation of the mean propagation angle for the same mean wind angles as in (a).

RELATED PROJECTS

The work, here tied to CBLAST, is also related to the NOPP Surf Zone Project which motivated the paper on oscillatory boundary layers (Mellor 2002) which is specialized to shallow water. Now, the Mellor 2003 and 2004 papers should provide under-pinnings for the type of work by John Allen and Priscilla Newberger for shallow water but which will also be applicable to deep water. Thus my research for CBLAST and for NOPP has merged.

REFERENCES

Craig, P. D. and M. L. Banner, 1994: Modeling wave-enhanced turbulence in the ocean surface layer. *J. Phys. Oceanogr.*, **24,** 2546-2559.

Jensen, B. L., B. M. Summer, and J. Fredsoe, 1989: Turbulent oscillatory boundary layers at high Reynolds numbers. *J. Fluid Mech.*, **206,** 265-297.

McWilliams, J. C. and J. M. Restrepo, 1999: The wave-driven ocean circulation. *J. Phys. Oceanogr.*, **29,** 2523-2540.

Mellor, G. L. and T. Yamada, 1982: Development of a turbulent closure model for geophysical fluid problems. *Rev. Geophys.*, **20,** 851-875.

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Phillips, O. M., 1977: *The Dynamics of the Upper Ocean, Cambridge University*. Cambridge University Press, Cambridge, 261 pp.

Terray, E. A., M. A. Donelan, Y. C. Agrawal, W. M. Drennan, K. K. Kahma, A. J. W. III, P. A. Hwang, and S. A. Kitaigorodski, 1996: Estimates of kinetic energy dissipation under breaking waves. *J. Phys. Oceanogr.*, **26,** 792-807.

PUBLICATIONS

Mellor, G. L., 2002: The oscillatory bottom boundary layer. *J. Phys. Oceanogr.*, **32,** 3075-3088

Mellor, G. L., 2003: The three dimensional, current and surface wave equations. *J. Phys. Oceanogr.*, **33,** 1978-1989 [published]

Mellor, G. L. and A. Blumberg, 2004: Wave breaking and surface layer thermal response. *J. Phys. Oceanogr.,***34***, 693-698.* [published]

Mellor, G. L. 2005: Some consequences of the three-dimensional current and surface wave equations. *J. Phys. Oceanogr.* [in press]

Mellor, G. L. and M. A. Donelan, 2006. A combined wave current numerical model: Part I, the wave model. J. Phys. Oceanogr.